The Effect of the 1995 Heat Wave in Chicago on All-Cause and Cause-Specific Mortality

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In light of the recent heat waves in the United States[1] and Europe[2] in July 2006, the devastating heat wave in Europe in 2003,[3] and the potential increase of such extreme weather events with climate change,[4] preparedness efforts need to be strengthened, including a better understanding of the population groups at highest risk. Although the effects of high temperatures on mortality have been widely studied,[5] few studies have used advanced time-series methods and measured mortality displacement during heat waves. Even fewer studies have used such methods to analyze specific heat wave periods,[6,7] and none of these studies has addressed heat waves on the North American continent.

We reexamined all-cause and cause-specific mortality during the 1995 Chicago heat wave with advanced time-series methods that allowed for control of the meteorologic and air pollution variables and the estimation of mortality displacement.

METHODS

We obtained death certificates from the Illinois Department of Public Health for calendar years 1993–1997 for deaths occurring daily in Cook County, Ill (the county containing the city of Chicago; county population = 5 190 965 in 1995). We computed separate mortality counts for age (<75 years and ≥75 years), gender, race (White, Black, or other), education (less than high school education, high school, or post–high school education), sudden death (defined as "outpatient death" or "dead on arrival in emergency room"), and underlying cause of death as cardiovascular disease (based on *International Classification of Diseases, Ninth Revision* [*ICD-9*][8] codes 390–429) or excessive heat (*ICD-9* code 900). Deaths from accidental causes (*ICD-9* codes higher than 800, except *ICD-9* code 900) were excluded from the analysis. The proportion of missing values was less than 1% for all of the variables except education (7.1%). Weather data were obtained from the weather station at O'Hare Airport in Chicago and air pollution data from the Environmental Protection Agency Aerometric Information Retrieval System database. Particulate matter less than 10 μm in diameter (PM_{10}) was used as a surrogate for total air pollution. Cook County has different schedules for monitoring particulate matter; the method of computation of PM_{10} exposure in Cook County has been described elsewhere.[9]

All-cause and cause-specific mortality data were analyzed using time-series methods using Poisson regression models that allowed for overdispersion. We controlled for possible confounders, including temporal trends, seasonal patterns, day-of-week effects, minimal temperature on the current day, maximal temperature the previous day, dew point temperature, and a 2-day moving average of PM_{10} for air pollution. The weather and air pollution variables were included in the models to capture the expected effects of these variables on daily mortality independent of the heat wave. Temperature and season variables were modeled using penalized cubic regression splines, an advanced statistical technique to create smoothed curves of data that exhibit complex variation.[10] The degree of smoothing of the spline function for season was chosen to remove seasonal and long-term temporal trends and to minimize autocorrelation in the residuals. The penalty used in the cubic spline model mitigated the trade-off between overfitting the data and oversmoothing complex temporal fluctuations. To capture the effect of the heat wave, we included a 6-degree-of-freedom-penalized cubic regression spline function of time for a 50-day period around July 15, 1995, the day with the maximum number of deaths during the heat wave. The 50-day period was chosen to allow us to examine the possibility of short-term mortality displacement. The 6-degree-of-freedom curve captured the independent effect of the heat wave from the usual effect of season and temperature outside of the heat wave.

We also conducted a second analysis that modeled any heat wave effect on daily mortality only through meteorological variables.

Objectives. We sought to reexamine the effects of the 1995 Chicago heat wave on all-cause and cause-specific mortality, including mortality displacement, using advanced time-series analysis methods.

Methods. We used Poisson regression with penalized regression splines to model excess mortality and mortality displacement over a 50-day period centered on the day in which the heat wave temperature peaked, adjusting for meteorological and other variables. We controlled for temporal trends by using daily mortality data during 1993–1997. We estimated relative risks (RRs) with reference to the first day of the 50-day period.

Results. We estimated that there were 692 excess deaths from June 21, 1995, to August 10, 1995; 26% of these deaths were owing to mortality displacement. RR for all-cause mortality on the day with peak mortality was 1.74 (95% confidence interval = 1.67, 1.81). Risk of heat-related death was significantly higher among Blacks, and mortality displacement was substantially lower.

Conclusions. The 1995 Chicago heat wave substantially effected all-cause and cause-specific mortality, but mortality displacement was limited. Mortality risks and displacement affected Blacks disproportionally. Appropriately targeted interventions may have a tangible effect on life expectancy. (*Am J Public Health.* 2007;97:S158–S162. doi:10.2105/AJPH.2006.100081)

TABLE 1—Distribution of Variables for Daily Mortality, Temperature, and Particulate Matter Less Than 10 μm in Diameter (PM_{10}): Chicago, 1993–1997

Variable	25th Percentile	Median	75th Percentile
Daily deaths	112	122	132
Daily deaths, age ≥ 75 y	54	60	67
Cardiovascular deaths	38	42	48
Temperature, °C	1.1	9.4	19.4
Dew point temperature, °C	-2.8	3.9	13.3
PM_{10}, μg/m³	22.6	31.4	42.4

For this analysis, we used minimum and maximum temperatures as independent variables for the current day. To allow for a potential delay in temperature effects, we also included 1-day, 2-day, and 3-day lags of these variables, instead of specifically fitting the heat wave with a time function. All of the variables were modeled using the same penalized cubic regression splines described in the previous paragraph, including the effect of same-day temperature. Interactions between l-day and 2-day temperatures were modeled using thin plate regression splines, a type of penalized spline that uses a nonparametric function to model the nonlinear relationship between temperature and time.[11] To ensure the capture of any sudden increase in mortality with temperature, we included a knot for every 1°F. Knots define the endpoints of different rules of regression splines. The choice of temperature terms, lags, and need for interactions was based on the Akaïke Information Criteria,[12] a measure of goodness of fit that accounts for the number of variables included in the model. We used the MGCV package (R Foundation for Statistical Computing, Vienna, Austria) in the R software environment for the analysis.[13]

RESULTS

Table 1 shows the distribution of all-cause and cause-specific daily mortality, temperature, dew point temperature, and PM_{10} in Cook County during the years 1993−1997. The highest temperature between June 22 and August 10, 1995, was 40°C (104°F) on July 13, 1995, and mortality peaked 2 days later, on July 15, 1995, when a total of 439 deaths were recorded (Figure 1). The peak

in all-cause mortality was mostly composed of cardiovascular and heat-related mortality; other causes of mortality, including respiratory disease, did not follow the same temporal pattern (Figure 1). The main portion of excess mortality occurred during the week of July 14 through July 20, 1995, when average daily mortality increased to 241 deaths per day. Of the 1686 deaths recorded during that week, 80 (4.7%) were reported with an underlying cause of excessive heat, and 473 (28.1%) had excessive heat as a contributing cause of death; of those 473 deaths, 93.7% were reported with an underlying cardiovascular cause.

The relative risk (RR) of mortality for each day was computed as the relative increase in mortality compared with the first day of the analysis (June 21, 1995), based on the Poisson spline regression model. The RR for all-cause mortality on July 15, the day with the highest mortality, was 1.74 (95% confidence interval [CI]=1.67, 1.81; Table 2). There was little difference in RR for all-cause mortality on July 15, 1995, using deaths among persons aged 75 years or more or among persons with less than a high school education compared with that estimated using all deaths. However, the RR for persons with less than a high school education was considerably higher than that for persons with a high school education, and there were no overlaps between the 2 CIs. The RR of death on July 15 was significantly higher among Blacks and lower among Whites than was that estimated for all deaths (Table 2). Further stratifying these analyses on the basis of race by gender, age, and education had little effect on these estimates. The RR in the general population was even greater when only cardiovascular deaths and sudden deaths were considered (Table 2).
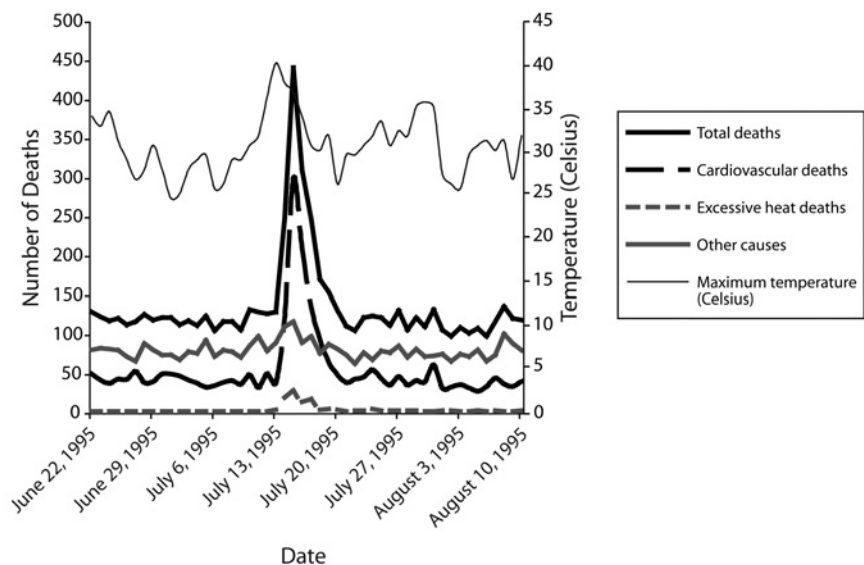

FIGURE 1— Daily number of deaths and maximum temperature during the Chicago heat wave: June 22, 1995–August 10, 1995.

TABLE 2—Relative Risk (RR; With 95% Confidence Intervals [CIs]) of Death on July 15, 1995: Chicago

Outcome	RR (95% CI)
All deaths	1.74 (1.67, 1.81)
Deaths, age ≥ 75	1.72 (1.63, 1.81)
Deaths, age < 75	1.59 (1.51, 1.68)
Male gender	1.79 (1.68, 1.89)
Female gender	1.64 (1.56, 1.72)
White race	1.52 (1.45, 1.59)
Black race	1.98 (1.86, 2.10)
Less than high school education	1.64 (1.55, 1.74)
High school or post–high school education	1.45 (1.36, 1.54)
Cardiovascular deaths	2.39 (2.22, 2.59)
Respiratory disease deaths	1.35 (1.23, 1.48)
Sudden deaths[a]	3.44 (3.22, 3.69)

Note. Relative risk was adjusted for long-term trend, season, day of the week, minimal temperature same day, maximal temperature 1 day before, dew point, and average of lag 0 to 1 of PM_{10}. July 15, 1995, was the day with the highest mortality during the Chicago heat wave that year.
[a]Sudden deaths were defined as "outpatient death" or "dead on arrival in emergency room."

FIGURE 2— Daily relative risk of death for all-cause mortality in the general population and among Blacks and Whites for a 50-day period during the Chicago heat wave: 1995.

On the basis of the fitted model, 692 excess deaths were estimated to have occurred between June 21 and August 10, 1995. There was some evidence of mortality displacement, with a reduction in deaths the week immediately after the heat wave. Mortality displacement was estimated at 183 persons (26.4% of total excess mortality) and was primarily found among Whites (Figure 2). Among 343 excess deaths among Whites, mortality for 128 (37.3%) was displaced; in contrast, mortality displacement was found for only 41 (12.8%) of 321 excess deaths among Blacks. In addition to a greater proportional increase than in Whites, a larger fraction of the excess deaths among Blacks were advanced in time by more than approximately 2 weeks.
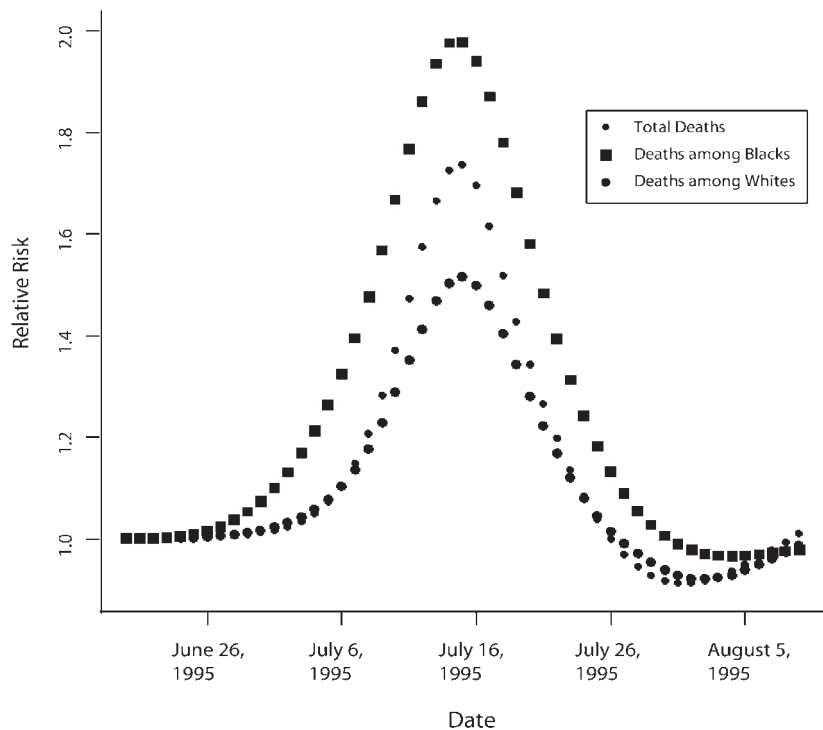
Lagged temperature models indicated the highest dose–response group relationship for lags of 1 and 2 days of high minimum or maximum temperatures before all-cause mortality occurred, with an RR of 1.20 (95% CI=1.15, 1.27) for high temperature on lag day 1 and an indication of a cumulative effect (RR=1.40; 95% CI=1.30, 1.51) when temperatures stayed high both on lag days 1 and 2.

DISCUSSION

Our study confirmed that the 1995 Chicago heat wave had substantial effects on all-cause and cause-specific mortality and showed that the heat wave resulted in mortality displacement that affected race disproportionally.

The greatest mortality was coded on death certificates as resulting from sudden death and cardiovascular causes. Our results indicated that low education had a protective effect for risk during the heat wave. The RR of death during the heat wave was substantially higher among Blacks than among Whites, confirming previous findings of increased rates of heat-related illness and death in the non-White or Black populations.[14–16] The higher risk of heat-related death for persons with less than a high school education indicates that differences in socioeconomic status among Blacks in the United States could explain these findings. However, other social factors may be equally important. Klinenberg[17] compared 2 neighborhoods in Chicago with similar socioeconomic conditions but with substantially different measures of social isolation and found no increased risk during the heat wave for the neighborhood with a high degree of social connectiveness but a substantial elevation in risk for the socially isolated neighborhood. The results of our study indicate that current heat-related interventions and warnings may not adequately address disparities and isolation in the Black community.

Mortality displacement affected only a quarter of total excess deaths. Even less evidence was found by the only other heat wave study that measured mortality displacement.[7] In our study, in particular, Black individuals who died during the heat wave were not expected to die of other causes in the immediate future. Therefore, interventions designed to prevent spikes in heat-related mortality during heat waves will have a tangible effect on life expectancy in populations at risk.

We were unable to examine the effect of social indicators other than education, such as income level or isolation, which may be more precise. Previous studies have indicated that such indicators may be important factors in heat-related mortality.[18,19] Our study was also not able to consider the potential effects of differences in levels of chronic disease or medication use that have been identified as personal risk factors for mortality during heat waves.[18–20]

When we removed temperature, dew point temperature, and air pollution from the model, the crude RR for all-cause mortality (1.76; 95% CI=1.69, 1.83) was not significantly different from the adjusted RR, showing that temporal variation in these factors did not substantially alter the effect of the heat wave. Modelers of heat waves are faced with the difficulty of separating heat wave effects from nonlinear temperature effects. We decided to include another variable in the model to specifically adjust for the heat wave period instead of using more degrees of freedom for temperature that may have induced an overfitting outside of the heat wave period. The regression spline function used to capture the effect of the heat wave allowed us to explain almost all of the increase in daily mortality, resulting in a rather limited effect of control for temperature on the mortality estimates. This finding was consistent with study results on the 2003 heat wave in France.[7]

Inclusion of daily ozone levels, instead of PM$_{10}$, into the model also had a negligible effect on RR for all-cause mortality (RR=1.72; 95% CI=1.65, 1.79). Because of the high correlation in the model between these measures during the summer months, only PM$_{10}$ was retained in the final model.

Models considering the temperature effect on the whole period indicated that 1 day of high minimum or maximum temperature, with a forecast of similar or increasing temperatures for the following day, may require immediate action to prevent excess mortality. The combination of high temperatures 1 and 2 days before the peak in number of deaths showed the highest risk of mortality, indicating the need to be prepared for an early and rapid activation of response plans.

As a consequence of the 1995 Chicago heat wave, heat-response plans have been implemented in US cities,[21,22] and surveillance activities have been improved.[23] Another heat wave in Chicago in 1999 resulted in considerably less mortality; however, differences in duration and meteorologic characteristics did not allow for attributing this to the city's heat-response activities.[22] Reports from the 1999 heat wave indicated that risk remains elevated for specific groups,[21,22] such as persons with mental illness or those living in group homes for people with mental illness.[21] Excess mortality during the devastating 2003 heat wave in Europe and, to a lesser extent, during the recent 2006 heat waves in the United States and Europe, have shown that extreme temperatures remain a major challenge to public health preparedness. ∎

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